Lattice Studies for a Small Storage Ring *

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Abstract

We have studied configurations of magnetic elements in order to maximize the beam brightness of a small e^- storage ring for use as a component in a Compton scattered x-ray facility. The design goal was a single bunch current of 20 mA at a beam energy of 125 MeV. The design produced a low emittance beam ($\varepsilon_x = 10^{-7}$ m-rad) with a reasonable lifetime. We plan to use NdBFe permanent magnetic driven dipoles in an attempt to reduce the overall cost of the storage ring facility, and the design used their properties for the bends in the lattice. Parameters varied include RF voltage, lattice structure, number and size of bend elements. In particular, the effect of intrabeam scattering at such a low energy was studied.

I. Introduction

We are working on the design of a small storage ring as part of a Compton scattered photon source of high brightness x-rays for protein crystallography. When the 10.6 μm wavelength (or 0.12 eV) energy photons of a CO_2 laser are scattered at right angles with a 100 MeV electron beam, x-rays of 9 keV are emitted in the direction of the electron beam. If a variable energy storage ring (80 to 125 MeV electrons) is used, then x-rays with energies between 5.7 and 14 keV are emitted. Since the brightness of the x-rays is determined by a combination of laser focus spot size and reasonably low electron angular divergence (1 mrad), the emittance of the ring must be

$$\varepsilon_x < 10^{-7} \text{ m} - \text{rad}$$

in the horizontal bend plane; the units of ε_x are such that the x distribution has an rms value of $\sqrt{\beta_x \varepsilon_x}$ for the Twiss parameter β_x.

One of the main goals of this study is to keep the ring small so that it will be inexpensive to build and operate. A related study [1] has shown that inexpensive permanent magnet-based dipoles should work well as the bend elements in the ring lattice, and the properties of those magnets have been assumed here. Initially it appeared that we could design a high brightness ring with square magnets and allow the beam to enter the dipoles at some angle other than at 90° to the iron face. This would generate considerable focusing and, perhaps, would allow a reduction in the number of quadrupoles and sextupoles in the lattice. We became suspicious of the computer programs' abilties to handle these iron face problems correctly at low energy, and decided to concentrate on "high quality" rings because there has not been too much work done in this low energy regime where intrabeam scattering is so important. Therefore, we have used a traditional, many element lattice in order to establish what we hope is a nearly optimum machine that can be used as a basis for comparison when simpler designs are studied.

II. Ring Specifications

The desired/achieved ring and stored beam properties are enumerated in Table I. Brightness requirements dominate the design, and intra-beam scattering leads to a search for longer bunch lengths, if possible, because internal bunch density will decrease without a corresponding loss in brightness. On the other hand, we will see that schemes for increasing bunch length will tend to cause reduced beam lifetime. There is also a need for a small β_x and β_y (0.1 and 1 m) in the insertion region for generating a small spot size at the collision point with the laser.

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Table I

Small Ring Parameters		
Parameter	Desired	This Design
Bend radius (m)	1	1
Circumference (m)	8	19
Beam current (mA)	300	-
One bunch (mA)	20	20
e^- Eng., max. (MeV)	125	125
e^- Eng., min. (MeV)	80	-
Life time (hour)	1	0.8
Bunch Length (cm)	10	2.8
ε_x (mm-mrad)	0.1	0.2

III. The Design

The main tools for this design are GEMINI [2] and ZAP [3] , computer programs which have been used extensively to design the LBL Advanced Light Source and its injector synchrotron [4]. Gemini was used to obtain a closed orbit solution(dispersion and chromaticity fit) and the natural horizontal emittance. ZAP calculated the equilibrium emittance due to intra-beam scattering and the Touschek lifetime as a function of RF voltage and beam current. Things assumed were 2 Ω longitudinal impedance, an RF frequency of 193 MHz (12th harmonic), and an $\varepsilon_x/\varepsilon_y$ ratio of 10:1.

The bend magnets were picked to be 0.4 m in length to acquire the appropriate deflection angle for the existing field strength in the dipole [1]. The pole faces were chosen perpendicular to beam to prevent problems with edge focusing effects at low energies. The actual lattice has 16 bends contained within a FODO lattice, and a quadrant is shown in Figure 1. The focusing quadrupoles are placed at each entrance to the insertion regions to obtain a small spot size. Table II lists the element parameters for the ring. The large strengths of the quadrupoles(k=20 and -15 m^{-1}) are used because of the small dimensions of the ring, and they produce large beta functions which deter intra-beam scattering. The beta functions and the dispersion are plotted in Figure 2 for a quadrant of the ring, staring at the insertion region. Sextupoles were placed to appropriately diminish any chromaticity present. Horizontal focusing sextupoles were placed where the ratio of the horizontal to vertical beta function is large and defocusing where the ratio is small. All other lattices tried did not have the small horizontal beta function at the insertion region.

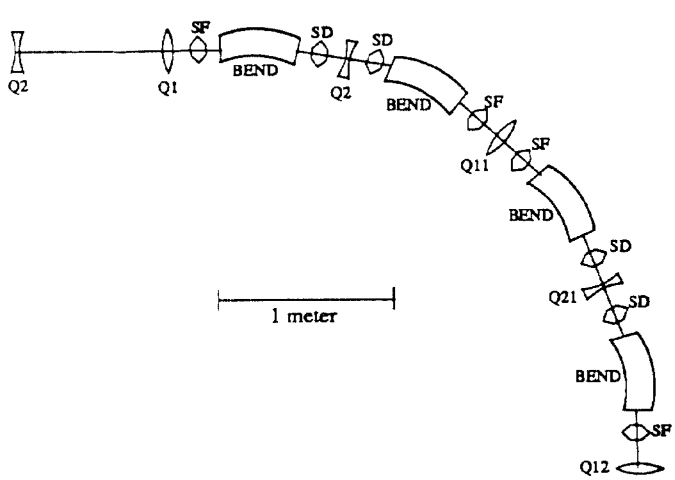

FIGURE 1. Quadrant of lattice starting at the insertion region. The distance between two quadrupoles is 0.85m.

Table II

Lattice Element Parameters		
Element	Length (m)	k (m^{-1})
Q_1 (=Q_{12})	0.1	20
Q_2 (=Q_{21})	0.1	-15
Q_{11}	0.1	20.6
SF	0.1	-3.4 m^{-2}
SD	0.1	2.7 m^{-2}
Bend	0.4	-0.41

IV. Results

One of the more interesting results of the study is shown in Figure 3. The horizontal emittance and the beam lifetime are plotted *vs* single bunch current for two RF cavity voltages. It is fairly clear that the low voltage, which allows a longer bunch length, will, however, lead to a significantly shorter beam lifetime. In the future we will try lower frequency RF solutions, but lower frequencies probably mean lower number of filled bunches in the ring and a lower total current.

We do not yet have a good solution for the insertion; the vertical size is too large ($\beta_y > 1$ m) and is located in the center of a quadrupole. Hopefully this can be fixed without too large an effect on the beam brightness. Overall, the ring looks quite promising for use as a Compton scattering x-ray source for protein crystallography, and future efforts should result in even simpler solutions with comparable brightness. We just

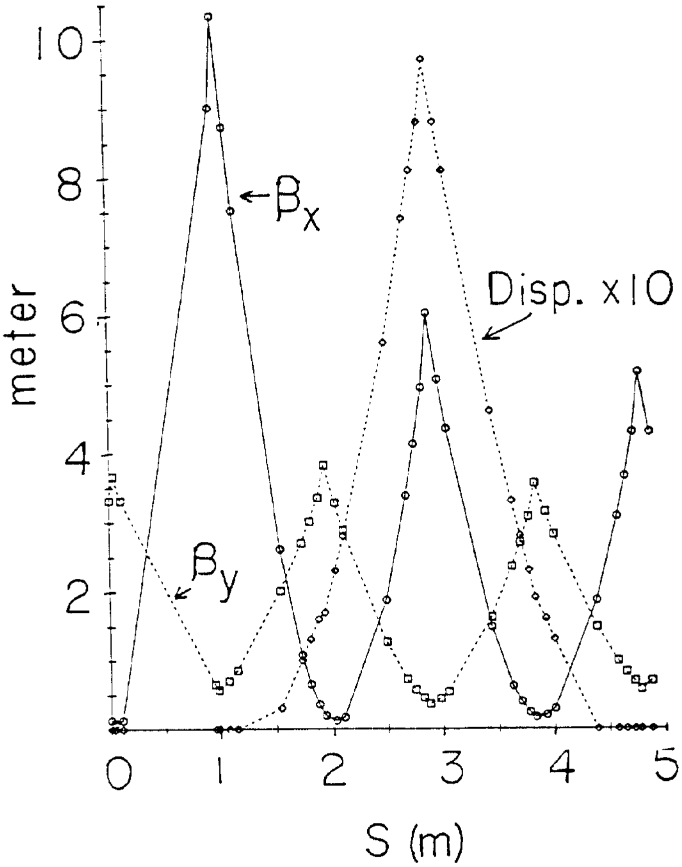

FIGURE 2. Horizontal, vertical beta functions, and 10xdispersion of quadrant starting at insertion region.

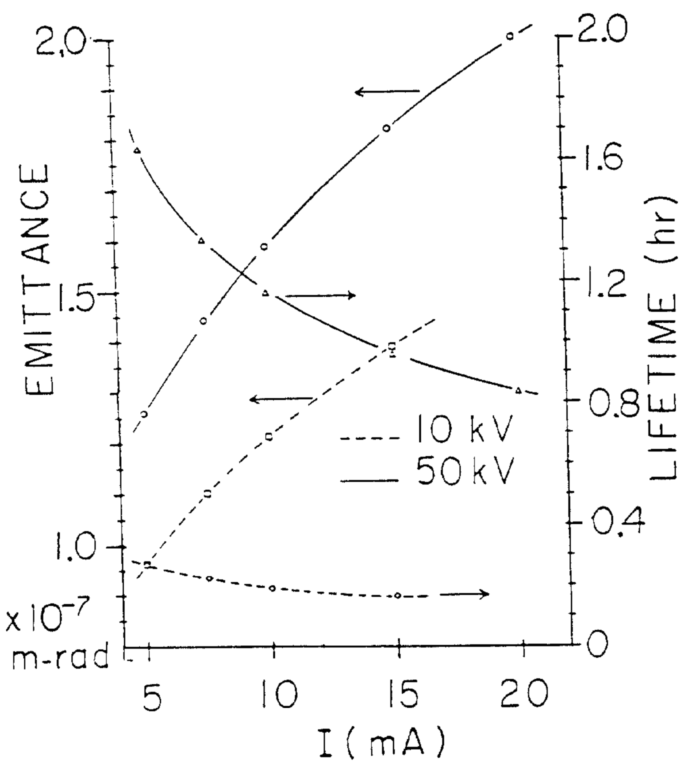

FIGURE 3. Emittance and Touschek lifetime vs. beam current for 50 & 10kV RF voltages.

learned of the SXLS project at BNL [5] in which 200 mA of current is being stored in a small ring at 80 MeV; if the emittance is low enough, that ring makes an excellent starting point for our needs.

V. Acknowledgements

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VI. References

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[5] "Commissioning of the Phase I Superconducting X-Ray Lithography Source (SXLS) at BNL," J. B. Murphy, *et al*, these proceedings.

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